# Fertigation in Micro-irrigated Horticultural Crops: Vegetables

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## Abstract

Fertigation is the injection of soluble nutrients into irrigation water to enhance crop production. In combination with micro-irrigation (drip irrigation), this technique forms an efficient method for precisely applying nutrients close to the crop root zone, especially when a polyethylene mulch is used. Vegetables are grown throughout the world on a wide variety of soil types and in various climates; China is the leading vegetable producer, followed by India and the United States. In most areas were vegetables are grown, mineral nutrients and irrigation must be provided to reduce nutrient and moisture stress and to maximize production. Where water is expensive or in short supply, drip irrigation is replacing surface and sprinkler irrigation; it is generally used in combination with polyethylene mulch on high-value crops, including tomato (*Lycopersicon esculentum*), pepper (*Capsicum annuum*), eggplant (*Solanum melongena*), strawberry (*Fragaria* × *ananassa*) , and cucurbits. Because soluble nutrients move with the wetting front, precise management of irrigation quantity, and rate and timing of N and K application are critical for efficient vegetable production. Drip irrigation can be scheduled to match the water evaporation from the crop or by use of such instruments as tensiometers. It is essential to avoid excessive irrigation and, on coarse textured soils, to apply only 30 to 40% of the N and K required for the crop at planting, with the remainder60 to 70% applied by fertigation. Generally other needed nutrients, including P, Mg, Ca, and micro-nutrients, are most efficiently applied preplant, in dry formulations and not by fertigation. For many vegetables, fertigation of N and K can be applied bi-weekly, weekly or daily. Drip fertigation systems are generally costly and require more management than seepage or sprinkler irrigation systems. With drip irrigation, water use is reduced, nutrient application is precise, diseases are reduced because the foliage remains dry, and yields of some corps are increased. With fertigation, nutrient use efficiency is increased and the risk of loss of nutrients to the ground water is reduced. Information from studies to support this production system is presented.

**Keywords:** drip irrigation, irrigation schedule, polyethylene mulch, nutrient source, nutrient application timing.

## Introduction

Fertigation is the application of soluble nutrients with via the irrigation water; its use in vegetable production has increased with the introduction of polyethylene mulch and drip irrigation, and it is an efficient means to apply fertilizer to the root zone. For efficient use of fertigation, water application and nutrient application must be precisely managed, to prevent over-watering and nutrient leaching. A wide variety of vegetables are grown throughout the world, on many soil types and in various climates. Soils commonly used to produce vegetables range from coarse-textured sands with water-holding capacity of 8 to 15% to fine-textured silt and clay soils with water holding capacities of over 40%. Soil textures vary from rocky and gravely to the widely used organic soils. Production areas range from humid with high rainfall to very dry or arid with little or no rainfall. In most areas where vegetables are grown successfully, irrigation is essential to supplement irregular rainfall, to minimize plant water stress (Doss, et. al., 1980; Locascio and Myers, 1974), and one or more mineral nutrients must be applied to maximize crop production (Hartz and Hochmuth, 1996). Highly inefficient surface irrigation is most commonly used worldwide, wherever water is abundant and inexpensive. Surface systems are inexpensive to install and easy to manage, but their water-use efficiency is lower (33%) than that of drip irrigation. Overhead sprinklers were introduced in the 1940's and are still used extensively on vegetables. The water flows to the field through conduits and is applied through overhead nozzles. These systems are more efficient (about 75% in the absence of mulch) and apply water more uniformly than surface irrigation, and can be used on uneven fields. However, they are more costly than surface irrigation systems, and are more complex to manage. In the 1950s, polyethylene mulch was introduced (Lamont, 2005) and its use drastically changed vegetable fertilization practices. With the so-called plasticulture, nutrient leaching is reduced, soil temperatures can be increased by the use of black mulch, most weeds are controlled, and yields are generally increased. Polyethylene mulch is now widely used on many vegetable crops worldwide. China leads the world in the use of polyethylene mulch for vegetables and in vegetable production, followed in vegetable output by India and the United States (Economic Research Service, USDA, 2005). In the 1960s, micro-irrigation (drip irrigation) systems were developed (Hall, 1971), and they are slowly replacing the more commonly used surface and overhead sprinkler systems in areas where the water supply is limited. However, drip systems are more costly and require a higher degree of maintenance and management than other irrigation systems. These highly efficient (about 90 to 95%) drip irrigation systems apply small amounts of water on a daily basis, through outlets (emitters) in low-pressure hoses placed close to the crop. Advantages of drip irrigation over other systems include: reduction of water use by over 50%; drier crops and row middles, which results in better insect and disease control; reduced weed growth in row middles; drier harvesting conditions; use of smaller pumps to provide small amounts of water daily, in contrast to large amounts applied on a 5- to 7-day schedule; and, very importantly, the ability to precisely control the application of plant nutrients (i.e., fertigation) and certain pesticides with the irrigation water (Locascio, 2005). Fertigation systems can be used without mulch, similarly to all irrigation systems, but are most efficiently used with drip-irrigated, higher-valued polyethylene mulched vegetables, in areas were water availability is limited. The timing of irrigation and nutrient application for polyethylene mulched, drip irrigated vegetables are discussed below.

## Watering schedule with drip irrigation

To minimize leaching of the soluble nutrients used with drip irrigation, and to maximize crop production, precise management of water application is essential, since over-irrigation results in nutrient leaching and reduced yields (Bar-Yosef, 1977). Even with fertigation, over-irrigation can result in severe nutrient deficiencies and reduced crop yields, e.g., excessive drip irrigation reduced tomato yield (Locascio *et al.*, 1989). Drip irrigation can be scheduled by matching a predetermined proportion of the water evaporated from a U. S. Weather Service Class A evaporation pan (E pan) (Phene *et al.*, 1973; Smajstrla *et al.*, 2000), which provides a measure of evapotranspiration (ET). Yields of polyethylene-mulched tomato were lower with drip irrigation at 2.0 E pan than at 1.0 E pan (Locascio *et al.*, 1981). On a coarse-textured soil yields of a spring tomato crop were higher when irrigated at 0.5 E pan than at 1.0 E pan (Locascio *et al.*, 1989), and the maximum yield was produced above 0.5 E pan, at about 0.75 E pan (Locascio and Smajstrla, 1989), whereas on a fine-textured soil, tomato yields were similar under irrigation at 0.5 and 1.0 E pan (Locascio *et al.*, 1989; Olson and Rhoads, 1992) with water application of 20 to 30 cm/ha, similar yields were obtained with one and with three irrigation applications per day on both soils. Pitts and Clark (1991) found that tomato water requirements varied from 0.2 E pan early in the season to 0.8 E pan during fruit development. Water scheduling according to pan evaporation often over-estimates early crop water needs: when tensiometer scheduling of water at 10 to 15 kPa was used, less water was applied than with 0.75 E pan application. On tomato, water used per crop was 30 cm with water scheduled to replace 0.75 E pan and 17 cm when irrigation was scheduled by means of magnetic switching tensiometers to apply sufficient water to maintain soils at 10 kPa (Locascio and Smajstrla, 1996; Smajstrla and Locascio, 1996). On finer-textured soils, sufficient water is applied to maintain the soil at 20 to 50 kPa (Locascio *et al*., 1992). In addition to tensiometers, soil water sensors and techniques that can be used to determine the time of irrigation include granular matrix sensors (GMSs) (Eldredge *et al*., 1993) and time-domain reflectometry (TDR) (Topp *et al*., 1984).

Soluble dyes can be applied with the irrigation water to track the depth of water and soluble-nutrient movement (Eger *et al*., 2001; Simonne *et al*., 2003). Excessive irrigation moves nutrients below the root zone and should be avoided.

## Nutrient requirements

The use of fertigation generally does not change the fertilizer requirements of a particular crop. Total fertilizer nutrient requirements vary with location, soil type, and crop (Hartz and Hochmuth, 1996). Most soils, except for organic soils, are deficient in N, which must be applied for most annual vegetables. Most mineral soils also lack P and K, which are applied to each crop. Needs for secondary and micro-nutrients vary widely according to the crop and the fertility of the soil, and the needs for P, K, secondary nutrients, and some micro-nutrients should be established by means of calibrated soil tests. Growers should use fertilizer recommendations developed by local scientists on the basis of soil fertility and crop needs, as exemplified by vegetables grown in Florida (Hochmuth and Hanlon, 1995).

The use of plasticulture often enables a double crop or a second crop to be grown after the initial crop. With drip irrigation, fertigation facilitates the application of nutrients for this second crop. Proper management of the first crop leaves little residual N and K for the second crop, which, therefore, should be fertigated with nutrients as required for a first crop (Clough *et al*., 1987). Soil tests should be used to determine the P and K requirements. Micro-nutrients applied for the first crop are generally sufficient for a double crop.

## Fertigated nutrients

All soluble nutrients can be applied effectively by fertigation with drip irrigation, but N and K are the main nutrients applied in this way, because they move readily with the irrigation water. All other needed nutrients generally can be applied most efficiently preplant. Fertigation P and most micro-nutrients move very poorly in the soil and do not reach the root zone. Needed P, secondary elements, and micro-nutrients are most efficiently applied preplant in the root zone. Use of fertigation to apply P and micro-nutrients together with Ca and Mg may cause precipitation and blockage of the emitters (Imas, 1999), and therefore should be minimized. When conditions require that P be applied by fertigation, it should be applied alone and the irrigation water should be acidified, to prevent clogging of the emitters (Rolston *et al*., 1981). Were micro-nutrient deficiencies occur and applications are made via fetigation, completely soluble sources or chelates can be used.

## Scheduling of N and K fertigation

The scheduling of nutrient application with drip irrigation is critical to the efficient use of nutrients, especially on coarse-textured soils, and requires some change in the way fertilizer is applied. When all nutrients were applied preplant in the bed, as with overhead- and surface-irrigated, polyethylene-mulched crops, both sprinkler and drip irrigation resulted in similar yields of tomato (Doss *et al*., 1980; Locascio and Myers, 1974) and of watermelon (*Citrullus lanatus*) (Elmstrom *et al*., 1981). When part of the N and K was applied preplant and part by fertigation with drip irrigation, yields were higher than with overhead irrigation for tomato (Locascio and Myers, 1974), muskmelon *(Cucumis melo)* (Shmueli and Goldberg, 1971), and strawberry (Locascio and Myers, 1975). With 100% preplant application of N and K, tomato yields were lower than when 50% was applied by fertigation (Dangler and Locascio, 1990). On a coarse-textured soil preplant application of all the P and of 40% of the N and K, with 60% of the N and K fertigated with drip irrigation tomato yields were greater than when all nutrients were applied preplant (Locascio and Smajstrla, 1989; Locascio *et al*., 1997b).

With drip irrigation on a coarse-textured soil, it is essential to supply only part of the N–K requirement via fertigation and to avoid over-irrigation. With part of the nutrients applied at planting, nutrient leaching is reduced, nutrient use efficiency is increased, and this generally results in higher yields than if all the nutrients were applied either preplant or through the drip system (Locascio *et al*., 1997b). In a 2-year study on fine-textured soils, however, yields were higher when 100% of the nutrients were applied before planting than when all or part of them were applied by fertigation (Locascio *et al*., 1997b). Split applications of nutrients were reported to maximize production of pepper (Hartz *et al*., 1993) and muskmelon (Bogle and Hartz, 1986). Preplant incorporation of N and K in the root zone provides nutrients for early growth during a period when irrigation may not be required, and before fertigation begins to supply nutrients throughout the bed as crop growth continues.

## Frequency of fertigation

Fertigation can be applied with each irrigation or on a scheduled basis to prevent nutrient stress. Since nutrient uptake increases with plant growth, some schedules ensure that the fertigation rate increases according to the crop growth curve. However, Locascio *et al*. (1997b) Locascio and Smajstrla (1989) found that with 40% preplant N and K application, similar yields were obtained with six 2-weekly or 12 weekly applications, either all equal or scheduled with initially small amounts that increased progressively with plant growth, and with daily or weekly fertigation. The frequency of fertigation – daily, weekly or 2-weekly – and whether the applications were uniform or increased progressively to match the plant growth were not critical, so that fertigation can be planned to suit the equipment available and the grower's convenience. Application of 100% of the N and K either preplant or by fertigation resulted in lower production than the split application (Locascio *et al*., 1989). On finer-textured soils, response to fertigation was not as consistent as on coarse ones, although N, and sometimes K, are most usually applied through fertigation to increase nutrient use efficiency. With subsurface drip-irrigation, broccoli (*Brassica oleracea* var. *italica*) yields were similar with fertigation at 1, 7, 14 and 28-day intervals (Thompson *et al*., 2003). It is apparent that to maximize crop yield on coarse-textured soils, 30 to 40% of the N and K must be applied preplant and the remainder by fertigation and that the actual schedule for fertigation is not critical.

## Fertigated N and K sources

All soluble nutrient sources are suitable for fertigation, and selection is generally according to the cost and the other element in the salt. Sources of N that perform similarly to one another in the fertigation of vegetables include ammonium nitrate, calcium nitrate, ammonium sulfate and potassium nitrate (Hartz and Hochmuth, 1996; Locascio *et al*., 1982; Locascio *et al*., 1984**,** Locascio and Martin, 1985). Also, urea can be applied via fertigation, but, studies have shown that nitrification of urea may be slow in fumigated soils (Fiskell and Locascio, 1983), and that some nitrate-N should be applied after soil fumigation, especially in cooler soils. Suitable K sources for fertigation include potassium chloride, potassium sulfate, and potassium nitrate, which generally perform very similarly to one another (Locascio *et al*., 1997a). Growers' concerns about the use of the chloride source are generally unfounded, except where saline water is used, where the soil is saline, or when application rates are excessive. On soils low in organic matter, S deficiencies may occur if some S-containing fertilizer is not applied either before planting or through fertigation; the required S can be supplied by applying part of the fertigated N or K in the form of S-containing fertilizers such as ammonium sulfate, ammonium thiosulfate, or potassium sulfate. On a low-S soil cabbage yields were higher when S was applied by fertigation than when applied preplant (Susila and Locascio, 2001); this indicates the importance of S fertigatiom on coarse-textured soils.

## Drip fertigation system components

Drip irrigation systems are complex and include pumps, backflow-prevention systems, filters, nutrient storage tanks, fertigation injectors, timers, and drip tubing. Clogging of emitters is a major concern, and efficient management and maintenance of the system are necessary (Imas, 1999). Drip irrigation and fertigation can be applied with smaller pumps than those used with other irrigation systems, since only a small amount of water is applied on a daily basis, which reduces pumping costs (Prevatt *et al.*, 1992). Because of the complexity of the numerous system components, drip/fertigation systems are more costly ($1,200/ha) than subirrigation system ($470/ha), therefore, drip/fertigation systems are used mostly in areas where water is scarce and costly, and on relatively high-value crops.

Fertigation is an efficient method to apply part of the fertilizer in a precise manner during the crop growing season. The nutrients most commonly applied in this way are N and K. Other nutrients are more efficiently applied preplant, in dry formulations. Efficient use of fertigation enables precise nutrient application, reduces the likelihood of nutrient leaching, and increases crop production.

## References

Bar-Yosef, B. 1977. Trickle irrigation and fertilization of tomatoes in sand dunes: water, N and P distribution in the soil and uptake by plants. Agronomy Journal 69:486-491.

Bogle, C.R., and T.K. Hartz. 1986. Comparison of drip and furrow irrigation for muskmelon production. HortScience 21:242-244.

Clough, G.H., S.J. Locascio, and S.M. Olson. 1987. Continuous use of polyethylene-mulched beds with overhead or drip irrigation for successive vegetable production. Proceedings of the National Agricultural Plastics Congress 20:57-61.

Dangler, J.M., and S.J. Locascio. 1990. Yield of trickle-irrigated tomatoes as affected by time of N and K application. Journal of the American Society for Horticultural Science 115:585-589.

Doss, B.D., J.L. Turner, and C.E. Evans. 1980. Irrigation methods and in-row chiseling for tomato production. Journal of the American Society for Horticultural Science 105:611-614.

Economic Research Service, USDA. 2005. Selected vegetable production in leading countries and the world, 1995-2004. Vegetables and Melons Outlook/VGS-309. http://www.ers.usda.gov/publications/vgs/tables/world.pdf

Eger, J.E., J.P. Gilreath, and J.W. Noling. 2001. Effect of irrigation times on wetting patterns in Florida vegetable soils. *In*: Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction, San Diego 2001, pp. 48-1 to 48-4.

Eldredge, E.P., C.C. Shock, and T.E. Stieber. 1993. Calibration of granular matrix sensors for irrigation management. Agronomy Journal 85:1228-1232.

Elmstrom, G.W., S.J. Locascio, and J.M. Myers. 1981. Watermelon response to drip and sprinkler irrigation. Proceedings of the Florida State Horticultural Society 94:161-163.

Fiskell, J.G.A., and S.J. Locascio. 1983. Changes in available N for drip-irrigated tomatoes from preplant and fertigation N sources. Soil and Crop Science Society of Florida Proceedings 42:180-184.

Hall, B.J. 1971. Comparison of drip and furrow irrigation for market tomato. Proceedings of the National Agricultural Plastics Conference 10:19-27.

Hartz, T.K., and G.J. Hochmuth. 1996. Fertility management of drip-irrigated vegetables. HortTechnology 6:168-172.

Hartz, T.K., M. LeStrange, and D.M. May. 1993. Nitrogen requirements of drip-irrigated pepper. HortScience 28:1097-1099.

Hochmuth, G.J., and E.A. Hanlon. 1995. IFAS standardized fertilization recommendations for vegetable crops. Florida Cooperative Extension Circular 1152.

Imas, P. 1999. Recent techniques in fertigation horticultural crops in Israel. *In*: IPI-PRII-KKV Workshop on: recent trends in nutrition management in horticultural crops, 11-12 Feb. 1999. Dapoli, Mahashtra, India. http://www.ipipotash.org/presentn/qaknhc.html.

Lamont, W.J. 2005. Plastics: Modifying the microclimate for the production of vegetable crops. HortTechnology 15:477-481.

Locascio, S.J. 2005. Management of irrigation for vegetables: past, present, and future. HortTechnology 15:482-485.

Locascio, S.J., and F.G. Martin. 1985. Nitrogen source and application timing for trickle-irrigated strawberries. J. Amer. Soc. Hort. Sci. 110:820-823.

Locascio, S.J., and J.M. Myers. 1974. Tomato response to plug-mix mulch and irrigation method. Proceedings of the Florida State Horticultural Society 87:126-130.

Locascio, S.J., and J.M. Myers. 1975. Trickle irrigation and fertilization method for strawberry. Proceedings of the Florida State Horticultural Society 88:185-189.

Locascio, S.J., and A.G. Smajstrla. 1989. Drip irrigated tomato as affected by water quantity and N and K application timing. Proceedings of the Florida State Horticultural Society 102:307-309.

Locascio, S.J., and A.G. Smajstrla. 1996. Water application scheduling by pan evaporation for drip-irrigated tomato. Journal of the American Society for Horticultural Science 121:63-68.

Locascio, S.J., J.M. Myers, and S.R. Kostewicz. 1981. Quantity and rate of water application for drip irrigated tomatoes. Proceedings of the Florida State Horticultural Society 94:163-166.

Locascio, S.J., J.M. Myers, and J.G.A. Fiskell. 1982. Nitrogen application timing and source for drip irrigated tomatoes. p. 323-328. *In* A. Scaife (ed.) Proceedings of the Ninth International Plant Nutrition Colloquium, Warwick Univ., Warwick, England, 1982.

Locascio, S.J., J.G.A. Fiskell, and F.G. Martin. 1984. Nitrogen sources and combinations for polyethylene mulched tomatoes. Proceedings of the Florida State Horticultural Society 97:148-150.

Locascio, S.J., S.M. Olson, and F.M. Rhoads. 1989. Water quantity and time of N and K application for trickle-irrigated tomatoes. Journal of the American Society for Horticultural Science 114:265-268.

Locascio, S.J, G.A. Clark, A.A. Csizinszky, C.D. Stanley, S.M. Olson, F. Rhoads, A.G. Smajstrla, G. Vellidis, R.J. Edling, H.Y. Hanna, M.R. Goyal, S. Crossman, and A.A. Navarro. 1992. Water and nutrient requirements for drip-irrigated vegetables in humid regions. Florida Agricultural Experiment Station Bulletin 363.

Locascio, S.J., S.M. Olson, R.C. Hochmuth, A.A. Csizinszky, and K.D. Shuler. 1997a. Potassium source and rate for polyethylene-mulched tomatoes. HortScience 32:1204-1207.

Locascio, S.J., G.J. Hochmuth, F.M. Rhoads, S.M. Olson, A.G. Smajstrla, and E.A. Hanlon. 1997b. Nitrogen and potassium application scheduling effects on drip-irrigated tomato yield and leaf tissue analysis. HortScience 32:230-235.

Olson, S.M., and F.M. Rhoads. 1992. Effect of water quantity on fall tomato production in north Florida. Proceedings of the Florida State Horticultural Society 105:334-336.

Phene, C.J., G.J. Hoffman, and R.S. Austin. 1973. Controlling automated irrigation with a soil matric potential sensor. Transactions of the American Society of Agricultural Engineers 16:773-776.

Pitts, D.J., and G.A. Clark. 1991. Comparison of drip irrigation to subirrigation for tomato production in southwest Florida. Applied Engineering in Agriculture 7:177-184.

Prevatt, J.W., G.A. Clark, and C.D. Stanley. 1992. A comparative cost analysis of vegetable irrigation systems. HortTechnology 2:91-94.

Rolston, D.E., R.S. Rauschkolb, C.J. Phene, R.J. Miller, K. Urier, R.M. Carlson, and D.W. Henderson. 1981. Applying nutrients and other chemicals to trickle-irrigated crops. California Division of Agricultural Science Bulletin 1893.

Shmueli, M., and D. Goldberg. 1971. Sprinkle, furrow and trickle irrigation of muskmelon in an arid zone. HortScience 6:557-559.

Simonne, E.H., D.W. Studstill, R.C. Hochmuth, G. McAvoy, M.D. Dukes, and S. Olson. 2003. Visualization of water movement in mulched beds with injections of dye with drip irrigation. Proceedings of the Florida State Horticultural Society 116:88-91.

Smajstrla, A.G., and S.J. Locascio. 1996. Automated drip irrigation scheduling of tomato using tensiometers. p. 845-850. *In*: Camp, C. R., E. J. Sadler, and R. E. Yoder (eds.). Evapotranspiration and irrigation scheduling. American Society of Agricultural Engineering San Antonio, TX.

Smajstrla, A.G., F.S. Zazueta, G.A. Clark, and D.J. Pitts. 2000. Irrigation scheduling with evaporation pans. Florida Cooperative Extension Service Bulletin 254. University of Florida, Gainesville, Fla.

Susila, A.D., and S.J. Locascio. 2001. Sulfur fertilization for polyethylene-mulched cabbage. Proceedings of the Florida State Horticultural Society 114:318-322.

Thompson, L.T., S.A. White, J. Walworth, and G.J. Sower. 2003. Fertigation frequency for subsurface drip-irrigated broccoli. Soil Science Society of America Journal 67:910-918.

Topp, G.C., J.L. Davis, W.G. Bailey, and W.D. Zebchuk. 1984. The measurement of soil water content using a portable TDR hand probe. Canadian Journal of Soil Science 64:313-321.